US007721397B2

(12) **United States Patent**
Chang et al.

(10) **Patent No.: US 7,721,397 B2**
(45) **Date of Patent: May 25, 2010**

(54) **METHOD FOR FABRICATING CAPACITIVE ULTRASONIC TRANSDUCERS**

(75) Inventors: **Ming-Wei Chang**, Taichung County (TW); **Tse-Min Deng**, Hsinchu (TW); **Te-I Chiu**, Taipei County (TW); **Mu-Yue Chen**, Kaohsiung (TW); **Da-Chen Pang**, Kaohsiung (TW); **Ping-Ta Tai**, Taipei (TW)

(73) Assignee: **Industrial Technology Research Institute**, Hsinchu (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 552 days.

(21) Appl. No.: **11/703,910**

(22) Filed: **Feb. 7, 2007**

(65) **Prior Publication Data**

US 2008/0188753 A1 Aug. 7, 2008

(51) **Int. Cl.**
H01G 7/00 (2006.01)

(52) **U.S. Cl.** **29/25.42**; 29/592.1; 29/594; 29/602.1; 29/609.1; 310/311; 310/333; 310/337; 310/357; 310/367; 324/633; 324/652; 324/655; 324/656; 347/54; 347/68; 347/69; 347/70; 347/72

(58) **Field of Classification Search** 29/25.42, 29/592.1, 594, 602.1, 609.1; 324/633, 652, 324/655, 656; 347/54, 68–72; 310/311, 310/333–337, 357, 367
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,295,247 B1 9/2001 Khuri-Yakub et al.
6,426,582 B1 7/2002 Niederer et al.
6,556,417 B2 * 4/2003 McIntosh et al. 361/278
6,632,178 B1 10/2003 Fraser
6,659,954 B2 12/2003 Robinson
2008/0235936 A1 * 10/2008 Chang et al. 29/594

OTHER PUBLICATIONS

Arif Sanli Ergun et al., "Capacitive Micromachined Ultrasonic Transducers: Fabrication Technology", IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 52, No. 12, pp. 2242-2258, (Dec. 2005), IEEE.

D. Memmi et al., "Fabrication of capacitive micromechanical ultrasonic transducers by low-temperature process", Sensors and Actuators A 99 2002, pp. 85-91, (2002), Elsevier Science B.V.

K.A.Wong et al., "Curved Micromachined Ultrasonic Transducers", 2003 IEEE Ultrasonics Symposium on Oct. 5-8, 2003, pp. 572-576, (2003), IEEE.

L.L.Liu et al., "A Novel Method for Fabricating Capacitive Micromachined Ultrasonic Transducers with Ultra-Thin Membranes", 2004 IEEE International Ultrasonics, Ferroelectrics, and Frequency Control Joint 50th Anniversary Conference, pp. 497-500, (2004), IEEE.

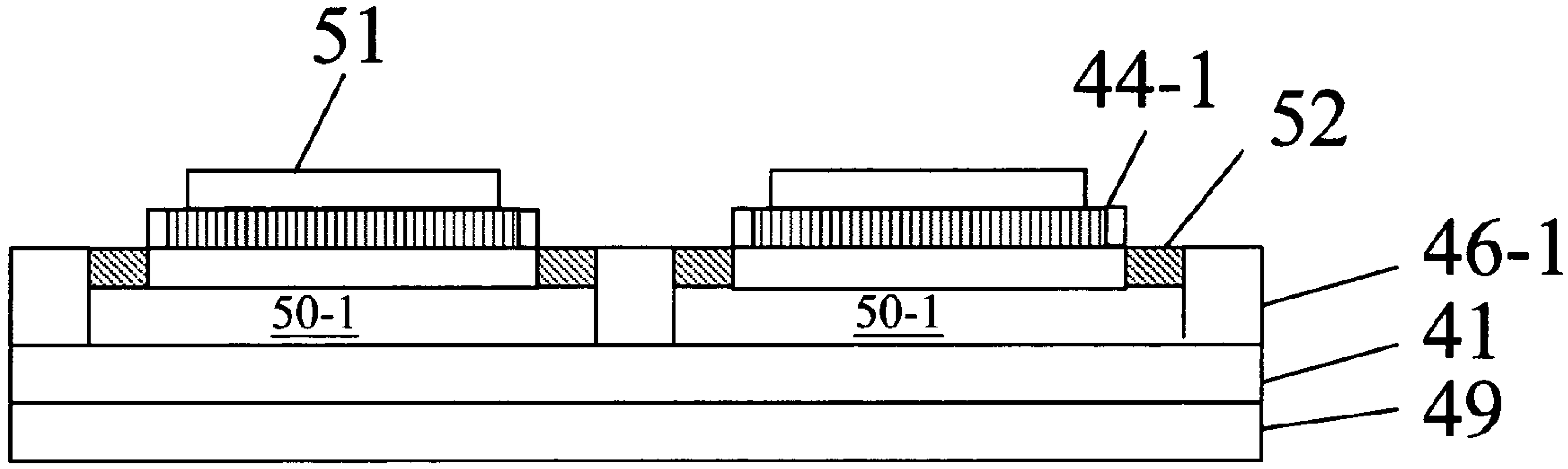
* cited by examiner

Primary Examiner—Paul D Kim
(74) *Attorney, Agent, or Firm*—Alston & Bird LLP

(57) **ABSTRACT**

A capacitive ultrasonic transducer includes a flexible layer, a first conductive layer on the flexible layer, a support frame on the first conductive layer, the support frame including a flexible material, a membrane over the support frame being spaced apart from the first conductive layer by the support frame, the membrane including the flexible material, a cavity defined by the first conductive layer, the support frame and the membrane, and a second conductive layer on the membrane.

15 Claims, 9 Drawing Sheets



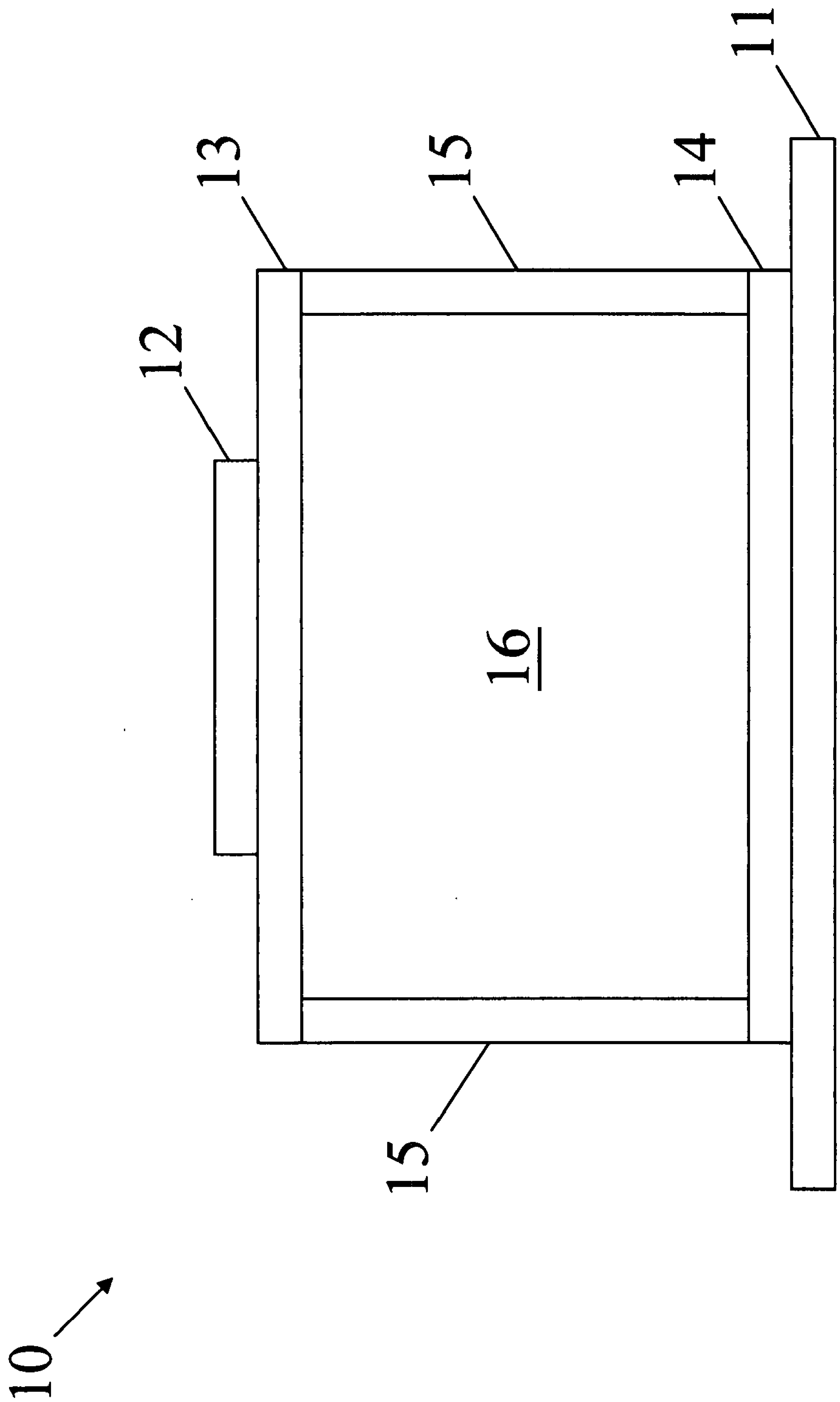


FIG. 1 (PRIOR ART)

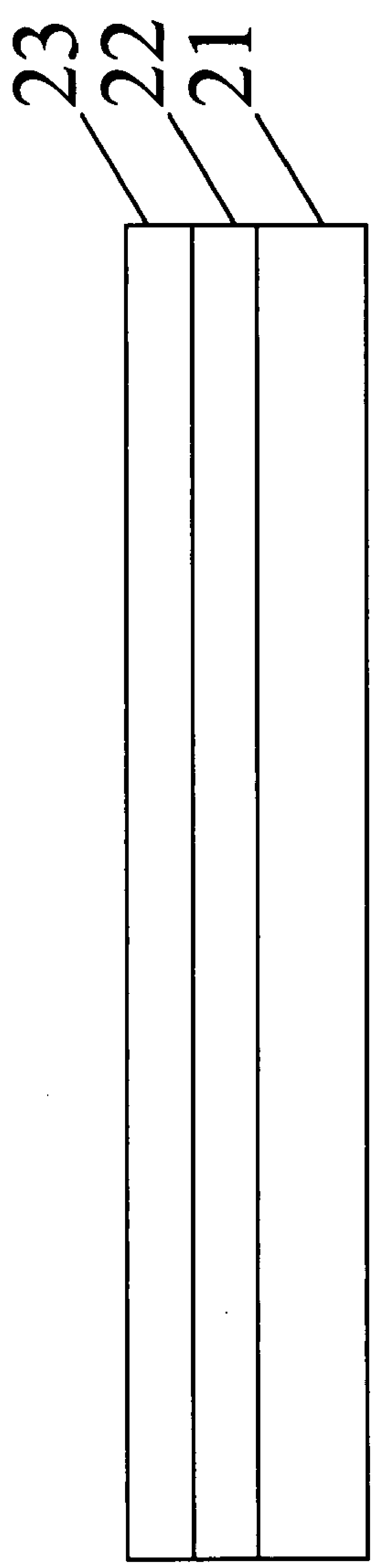


FIG. 2A (PRIOR ART)

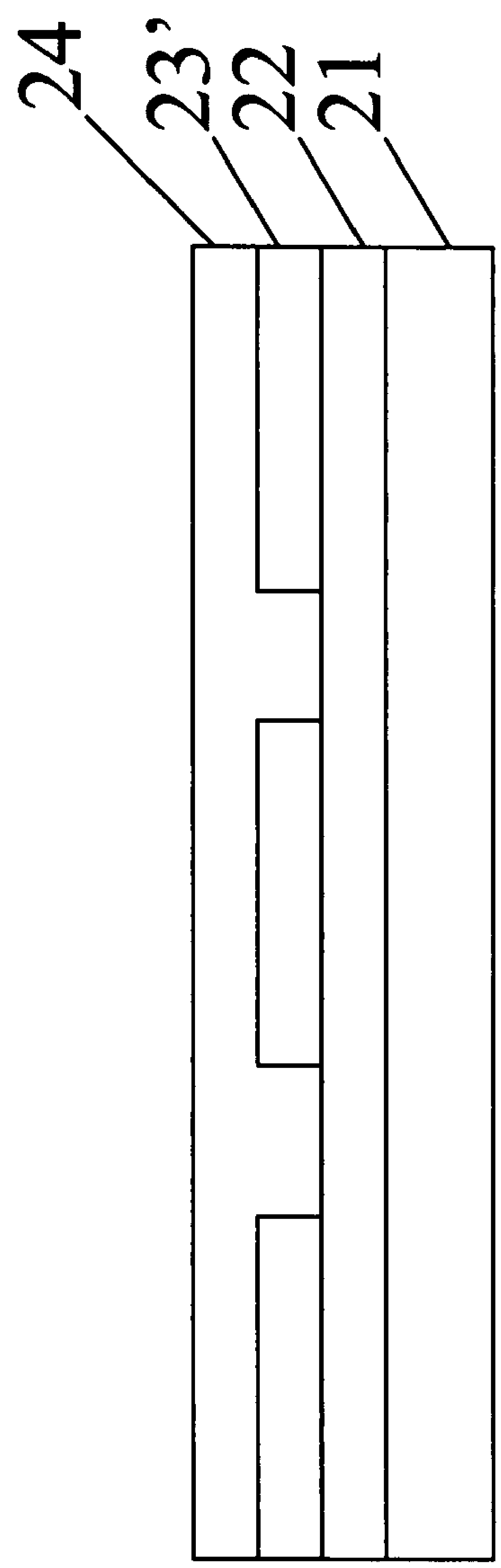


FIG. 2B (PRIOR ART)

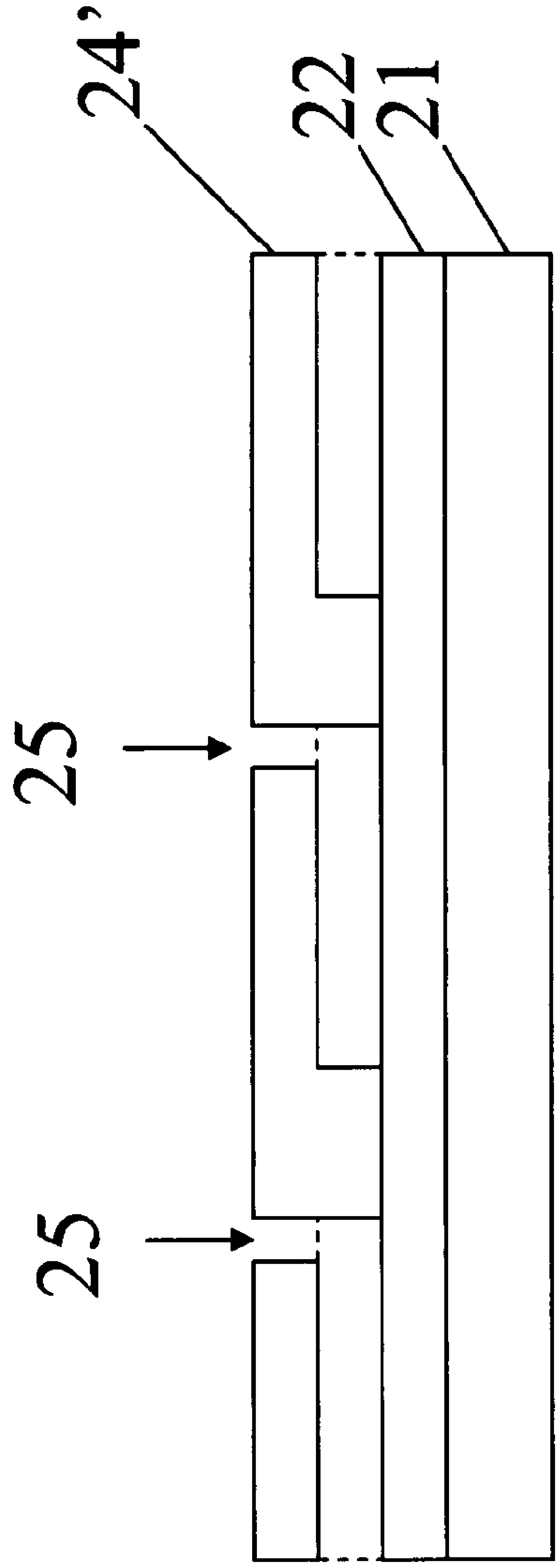


FIG. 2C (PRIOR ART)

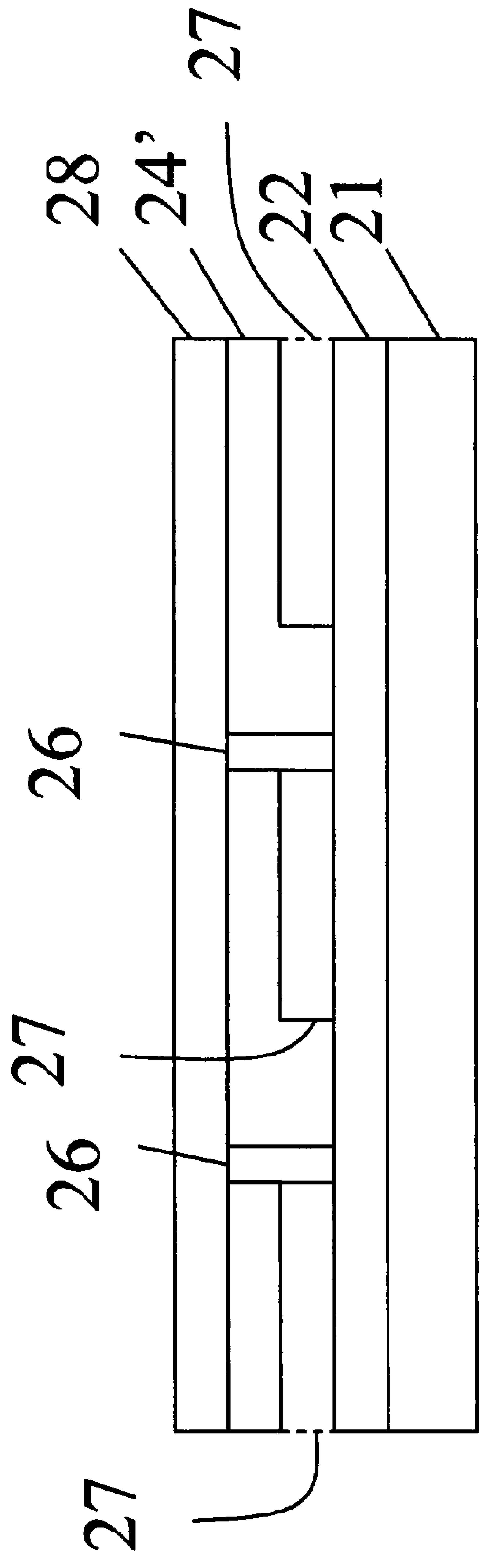


FIG. 2D (PRIOR ART)

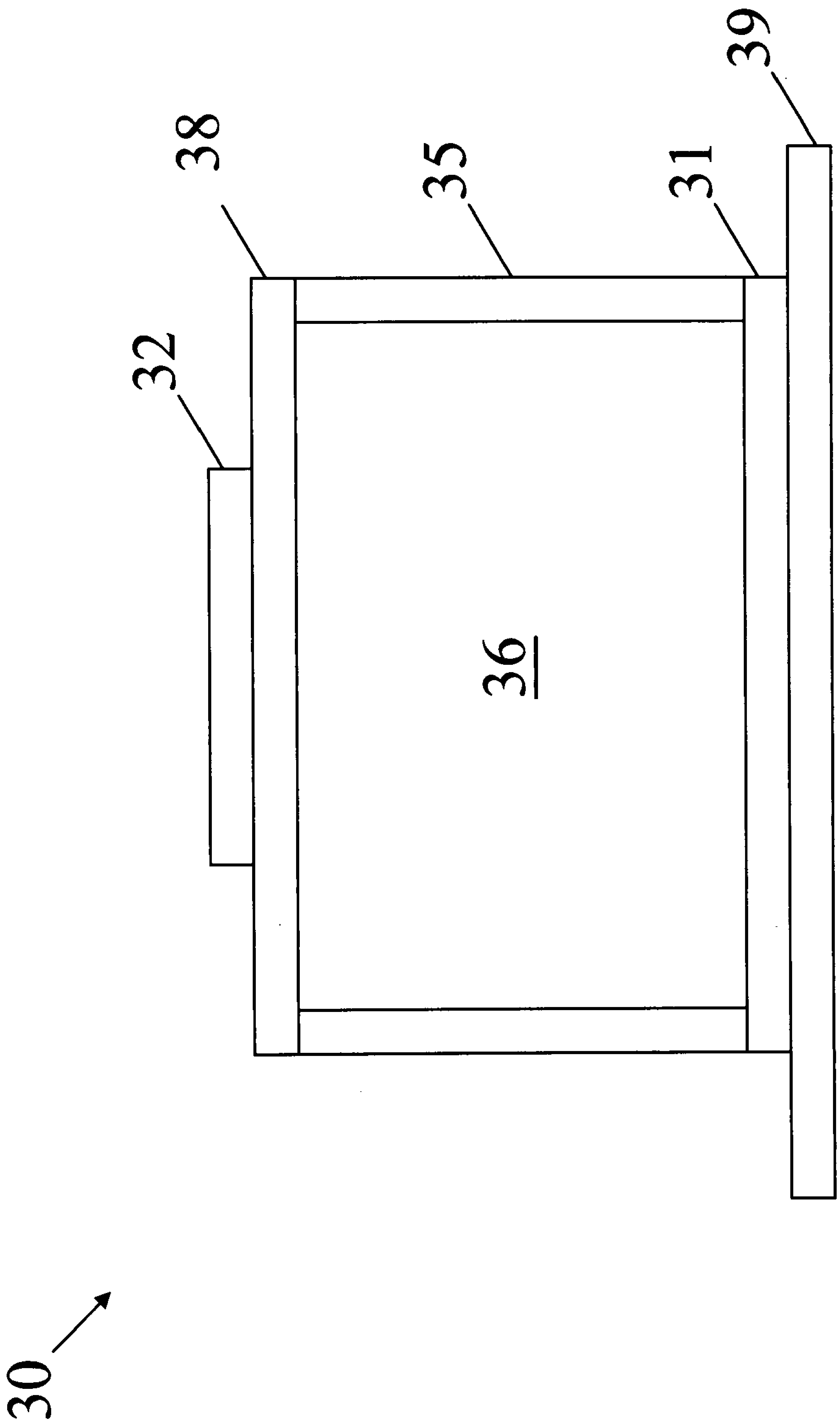


FIG. 3

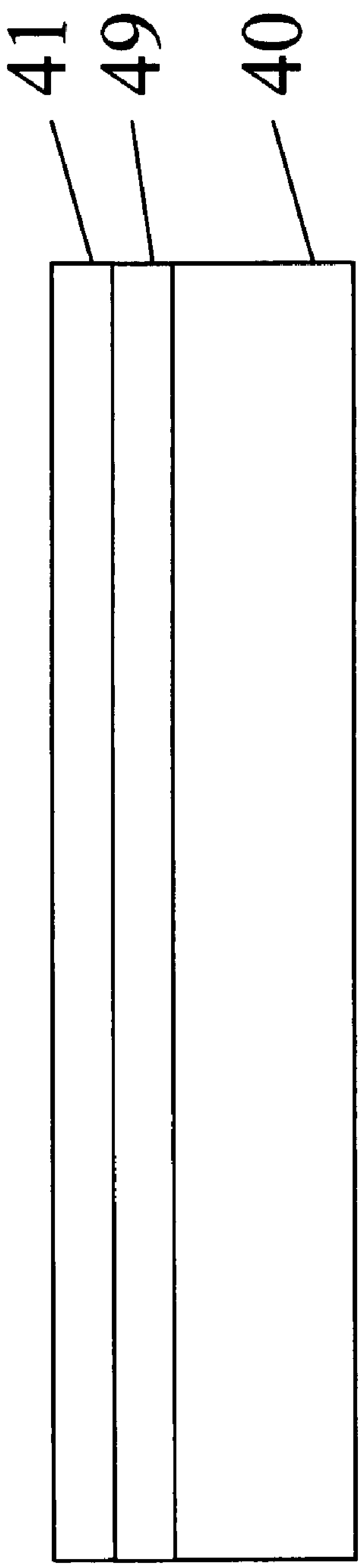


FIG. 4A

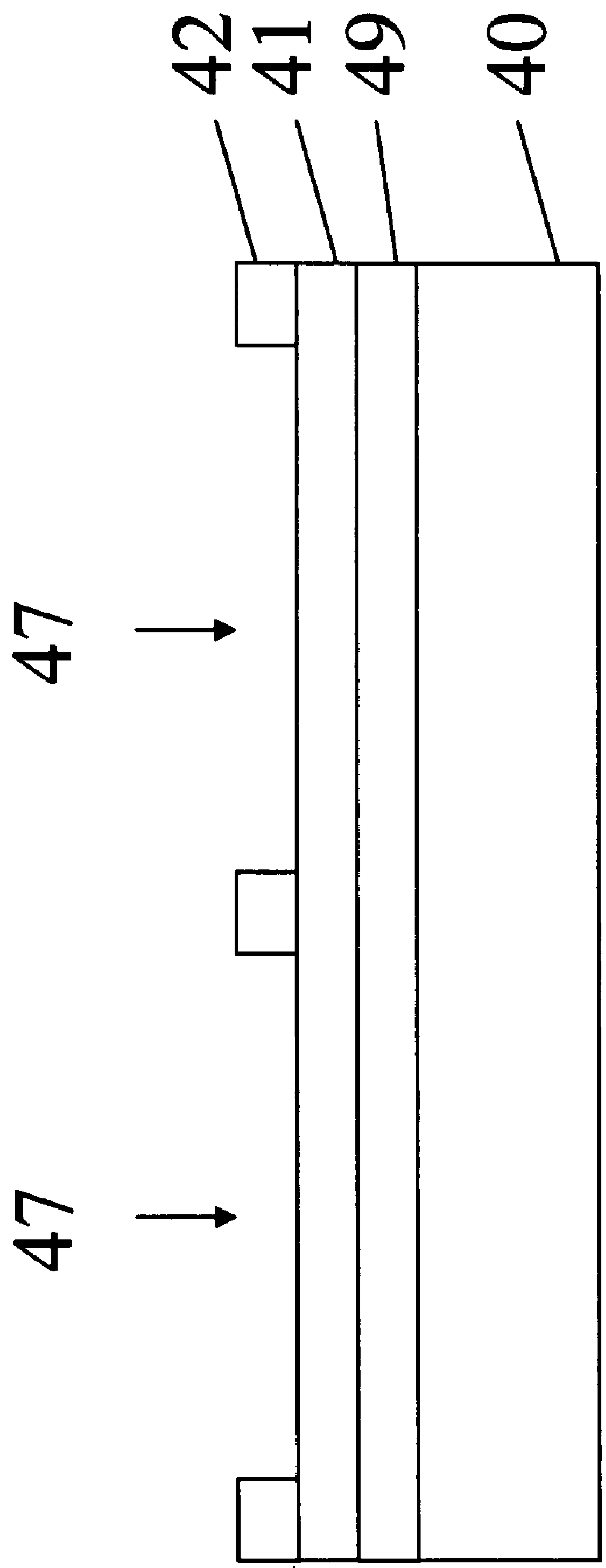


FIG. 4B

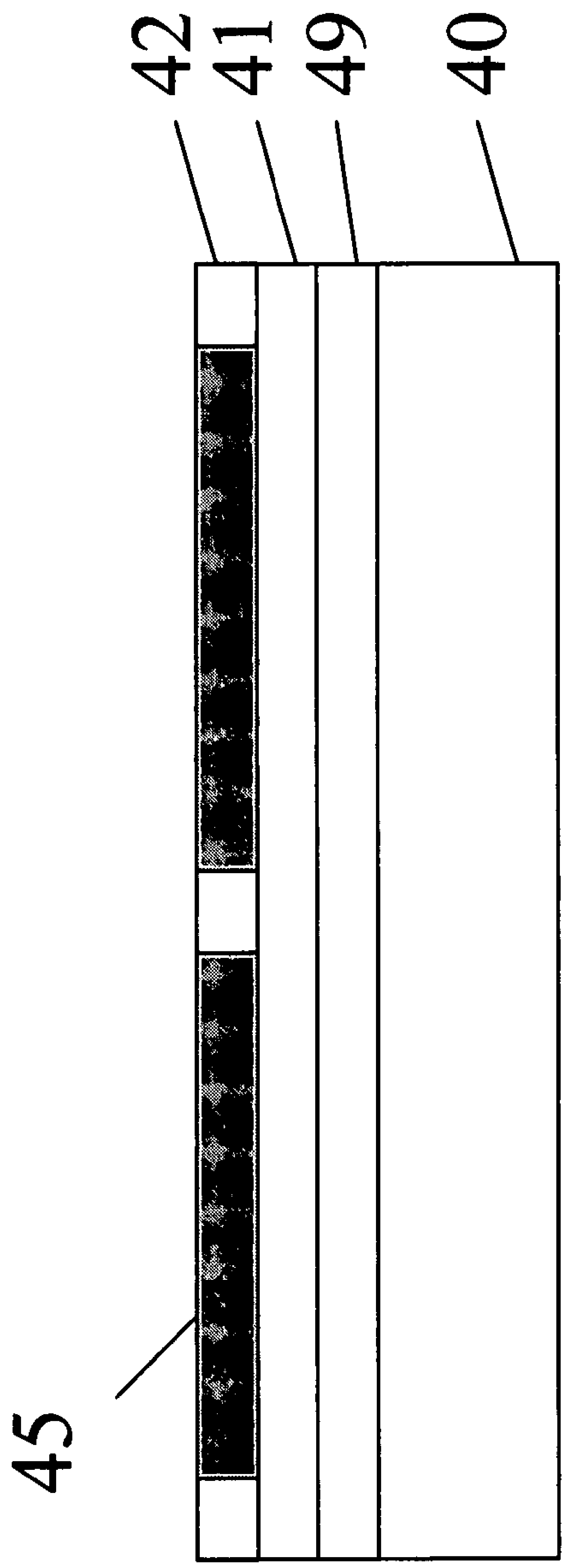


FIG. 4C

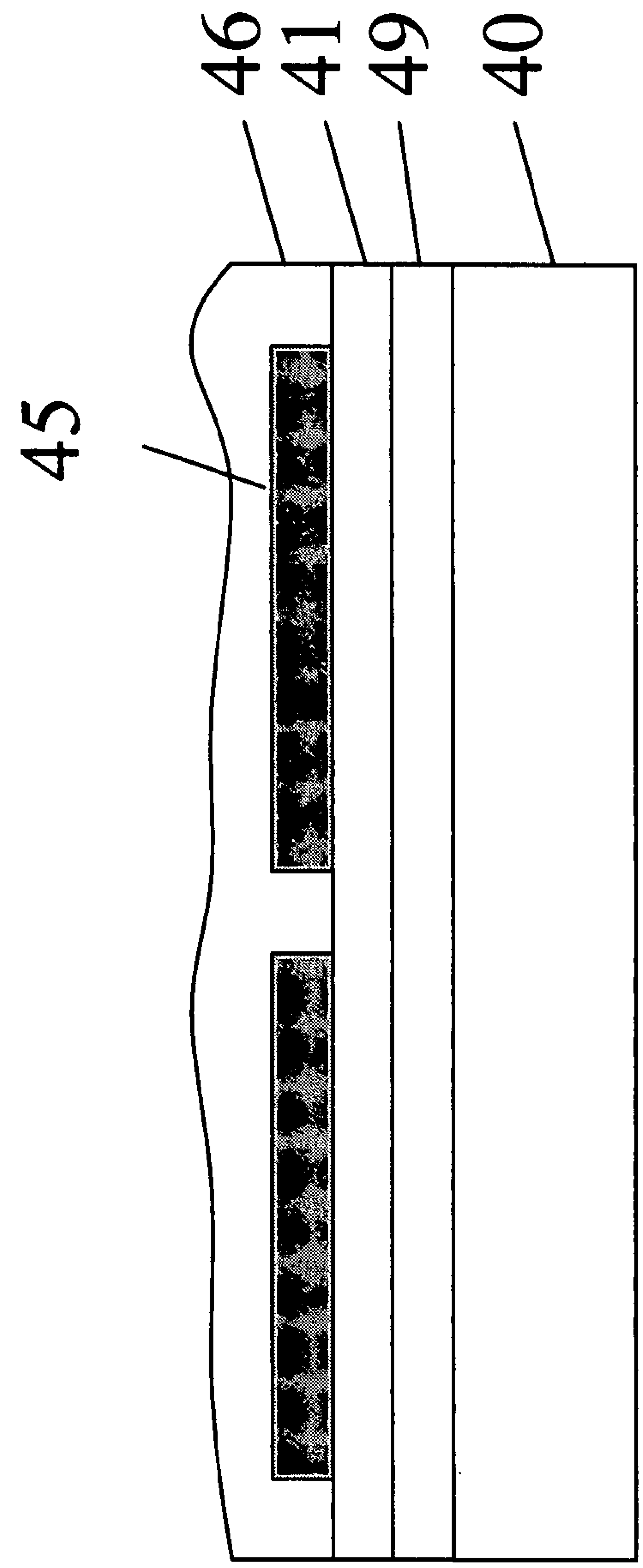


FIG. 4D

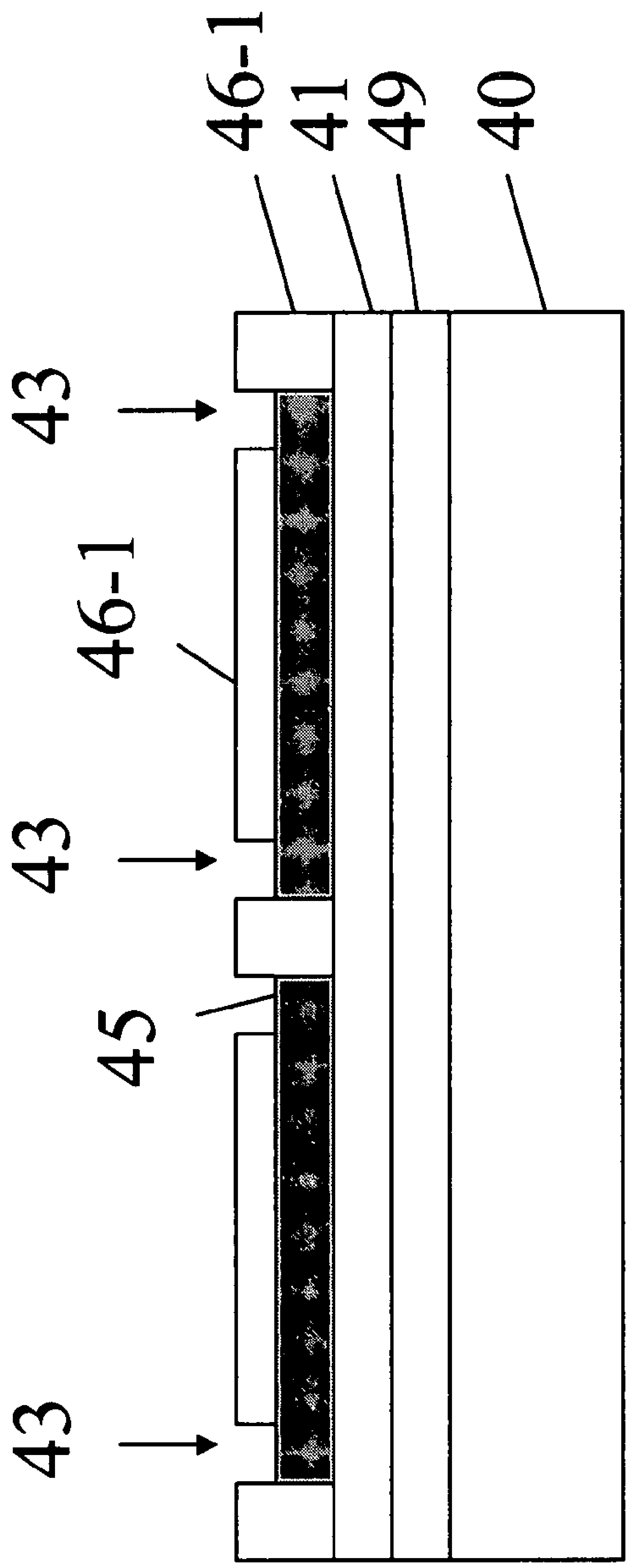


FIG. 4E

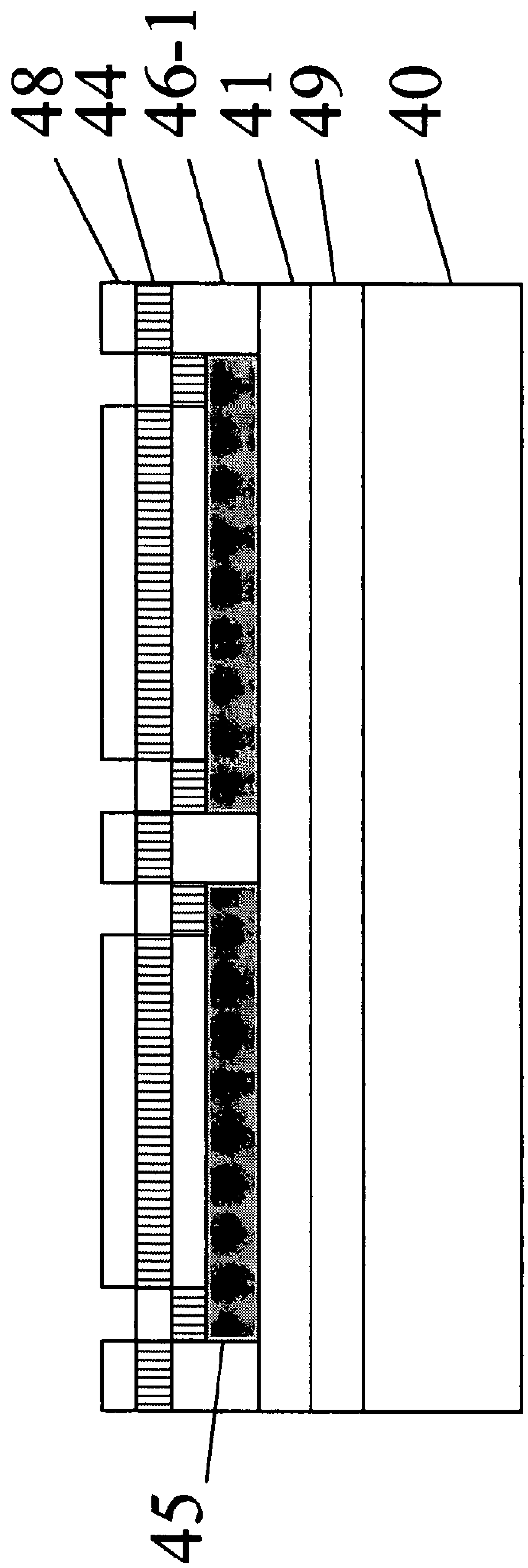


FIG. 4F

FIG. 4G

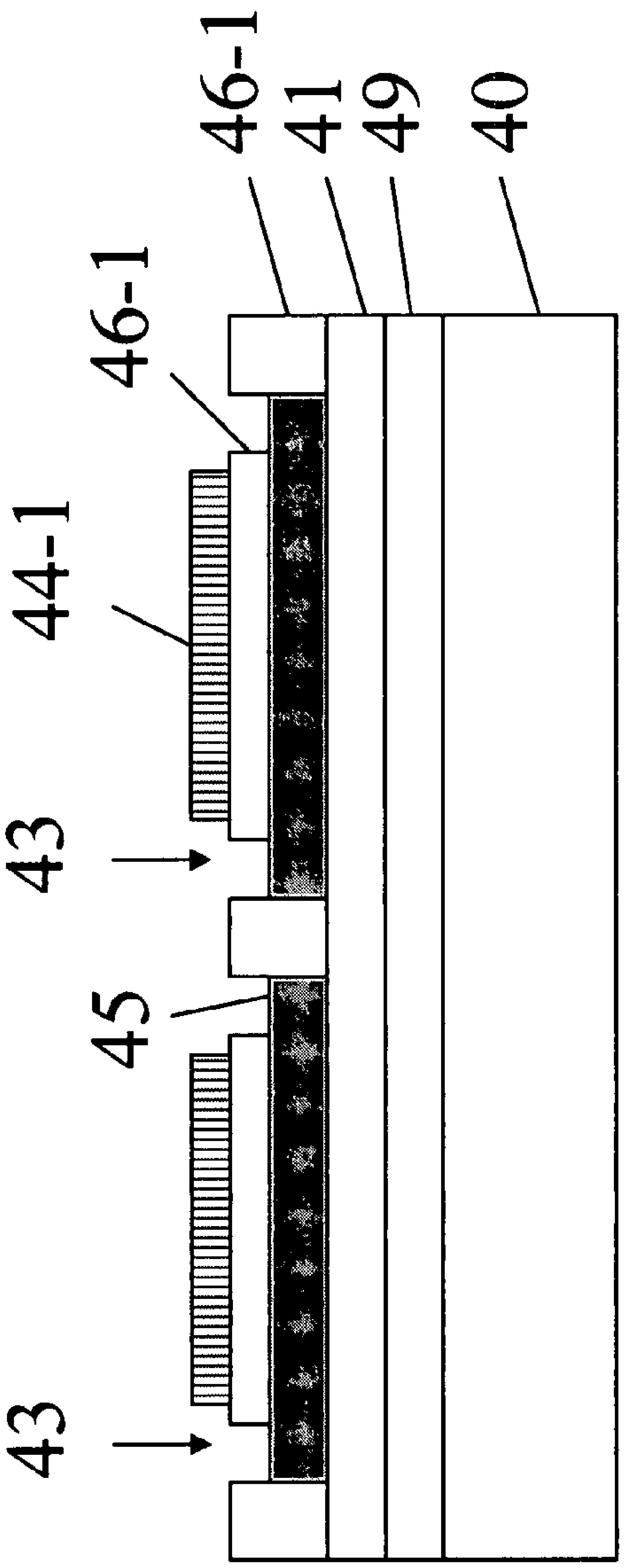
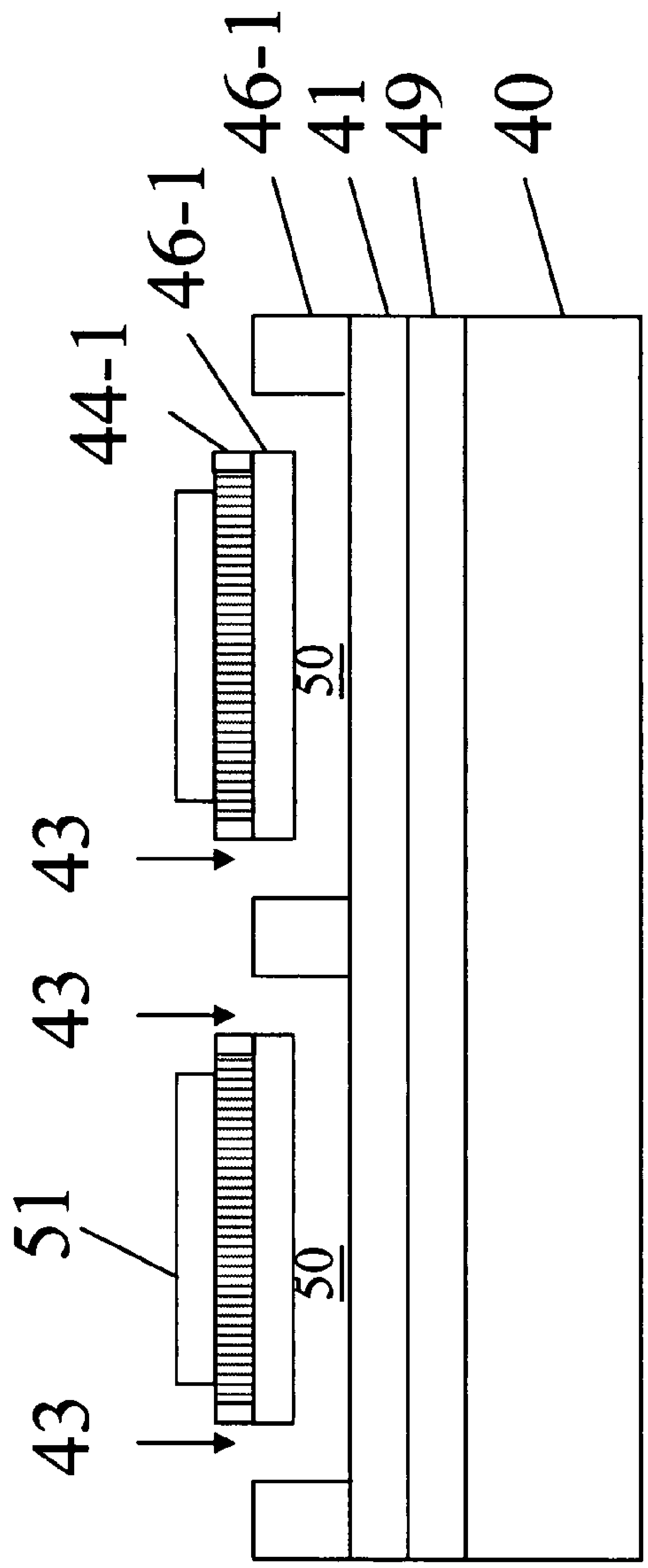


FIG. 4H



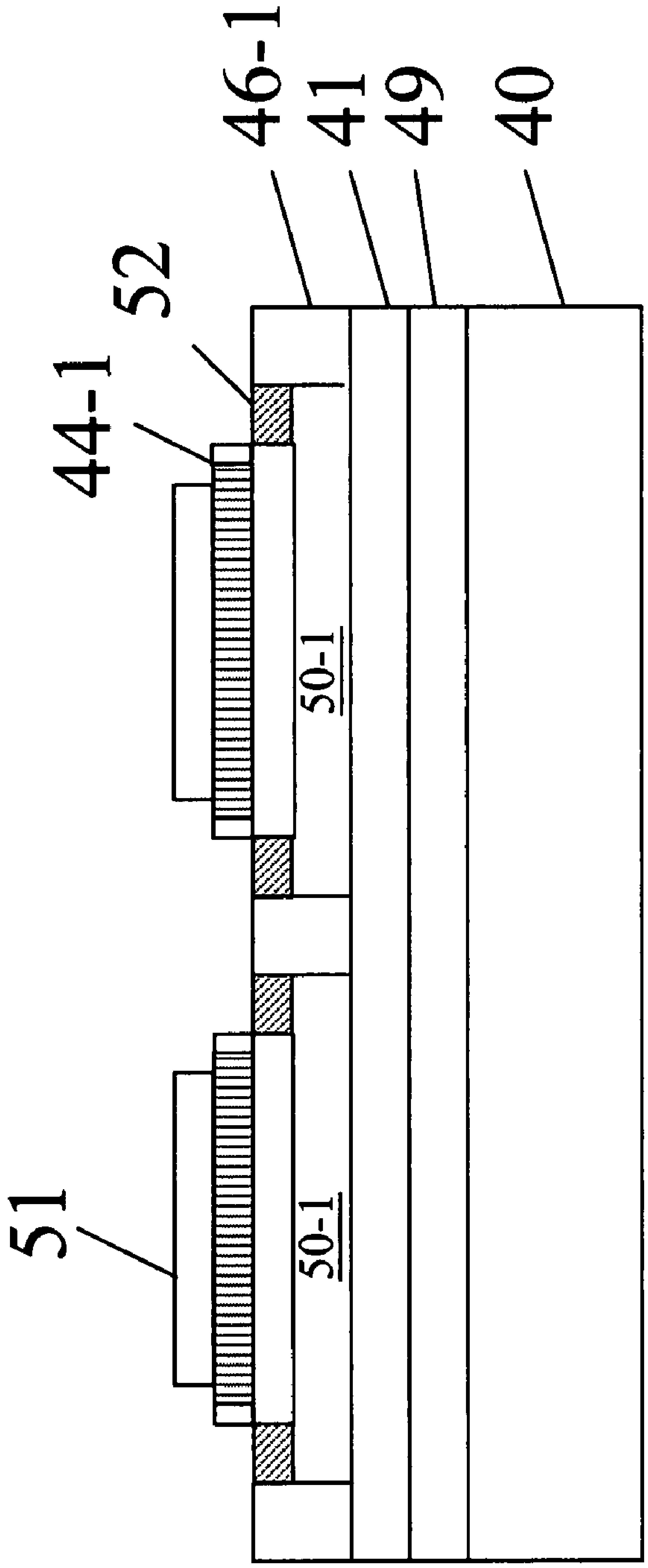


FIG. 4I

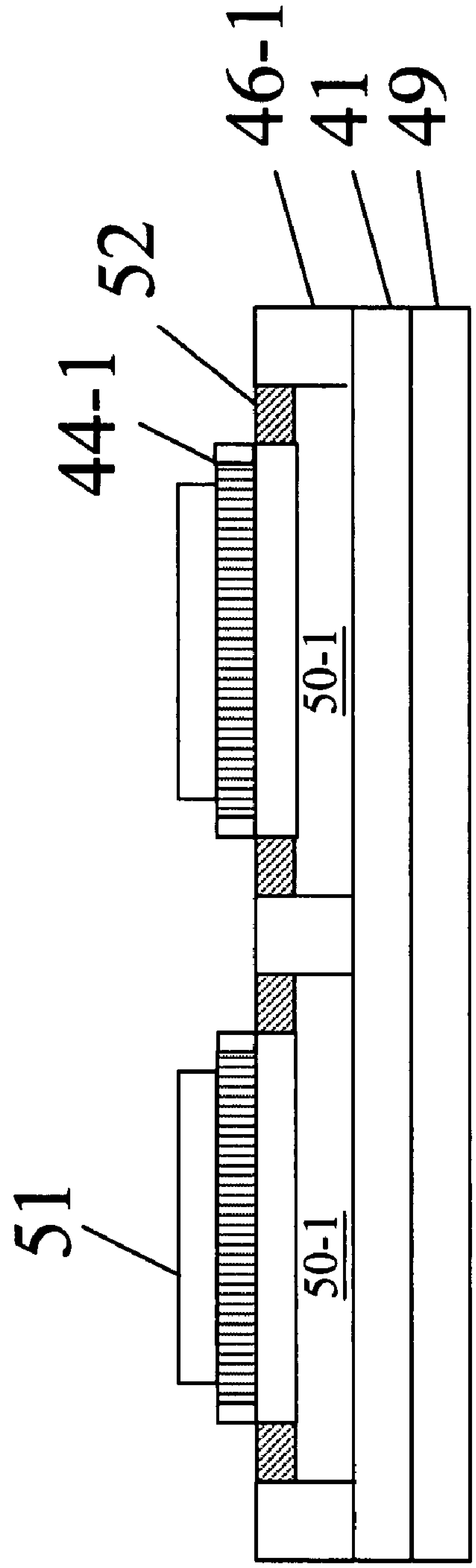


FIG. 4J

METHOD FOR FABRICATING CAPACITIVE ULTRASONIC TRANSDUCERS

BACKGROUND OF THE INVENTION

The present invention relates to an ultrasonic transducer and, more particularly, to a flexible capacitive ultrasonic transducer and a method of fabricating the same.

With the advantages of non-invasive evaluation, real-time response and portability, ultrasonic sensing devices have been widely used in medical, military and aerospace industries. For example, echographic systems or ultrasonic imaging systems are capable of obtaining information from surrounding means or from human body, based on the use of elastic waves at ultrasonic frequency. An ultrasonic transducer is often one of the important components in an ultrasonic sensing device. The majority of known ultrasonic transducers are realized by using piezoelectric ceramic. A piezoelectric transducer is generally used to obtain information from solid materials because the acoustic impedance of piezoelectric ceramic is of the same magnitude order as those of the solid materials. However, the piezoelectric transducer may not be ideal for obtaining information from fluids because of the significant impedance mismatch between piezoelectric ceramic and fluids, for example, tissues of the human body. The piezoelectric transducer may generally operate in a frequency band from 50 KHz to 200 KHz. Furthermore, the piezoelectric transducer may generally be fabricated in high-temperature processes and may not be ideal for integration with electronic circuits. In contrast, capacitive ultrasonic transducers may be manufactured in batch with standard integrated circuit ("IC") processes and therefore are integrable with IC devices. Furthermore, capacitive ultrasonic transducers are capable of operating at a higher frequency band, from 200 KHz to 5 MHz, than known piezoelectric transducers. Consequently, capacitive ultrasonic transducers have gradually taken the place of the piezoelectric transducers.

FIG. **1** is a schematic cross-sectional view of a capacitive ultrasonic transducer **10**. Referring to FIG. **1**, the capacitive ultrasonic transducer **10** includes a first electrode **11**, a second electrode **12** formed on a membrane **13**, an isolation layer **14** formed on the first electrode **11**, and support sidewalls **15**. A cavity **16** is defined by the first electrode **11**, the membrane **13** and support sidewalls **15**. When suitable AC or DC voltages are applied between the first electrode **11** and the second electrode **12**, electrostatic forces cause the membrane **13** to oscillate and generate acoustic waves. The effective oscillating area of the conventional transducer **10** is the area defined by the first electrode **11** and second electrode **12**. In this instance, the effective oscillating area may be determined by the length of the second electrode **12** because the second electrode **12** is shorter than the first electrode **11**. Furthermore, the membrane **13** may generally be fabricated in a high-temperature process such as a conventional chemical vapor deposition ("CVD") or low pressure chemical vapor deposition ("LPCVD") process at a temperature ranging from approximately 400 to 800° C.

FIGS. **2**A to **2**D are cross-sectional diagrams illustrating a conventional method for fabricating a capacitive ultrasonic transducer. Referring to FIG. **2**A, a silicon substrate **21** is provided, which may be heavily doped with impurities in order to serve as an electrode. Next, a first nitride layer **22** and an amorphous silicon layer **23** are successively formed over the silicon substrate **21**. The first nitride layer **22** may function to protect the silicon substrate **21**. The amorphous silicon layer **23** is used as a sacrificial layer and will be removed in subsequent processes.

Referring to FIG. **2**B, a patterned amorphous silicon layer **23'** is formed by patterning and etching the amorphous silicon layer **23**, exposing portions of the first nitride layer **22**. A second nitride layer **24** is then formed over the patterned sacrificial layer **23'**, filling the exposed portions.

Referring to FIG. **2**C, a patterned second nitride layer **24'** with openings **25** is formed by patterning and etching the second nitride layer **24**, exposing portions of the patterned amorphous silicon layer **23'** through the openings **25**. The patterned amorphous silicon layer **23'** is then removed by a selective etch.

Referring to FIG. **2**D, a silicon oxide layer is deposited through the openings **25** to form plugs **26**. Chambers **27** are thereby defined by the plugs **26**, the patterned second nitride layer **24'** and the first nitride layer **22**. A metal layer **28** is then formed over the patterned second nitride layer **24'** to serve as a second electrode.

However, the conventional capacitive ultrasonic transducer is inflexible due to the utilization of a silicon-based substrate. The inflexibility restricts the conventional capacitive ultrasonic transducer to a limited application. It may therefore be desirable to have a flexible capacitive ultrasonic transducer and a method of fabricating the same.

BRIEF SUMMARY OF THE INVENTION

Examples of the present invention may provide a capacitive ultrasonic transducer that comprises a flexible layer, a first conductive layer on the flexible layer, a support frame on the first conductive layer, the support frame including a flexible material, a membrane over the support frame being spaced apart from the first conductive layer by the support frame, the membrane including the flexible material, a cavity defined by the first conductive layer, the support frame and the membrane, and a second conductive layer on the membrane.

Some examples of the present invention may provide a method for fabricating capacitive ultrasonic transducers, the method comprising providing a substrate, forming a flexible layer on the substrate, forming a first conductive layer on the flexible layer, forming a patterned sacrificial layer on the first conductive layer, forming a first polymer layer over the patterned sacrificial layer, patterning the first polymer layer to provide a patterned first polymer layer, exposing portions of the patterned sacrificial layer through openings, forming a second conductive layer on the patterned first polymer layer, patterning the second conductive layer to provide a patterned second conductive layer, forming a second polymer layer over the patterned second conductive layer, patterning the second polymer layer, exposing portions of the patterned sacrificial layer through the openings, and removing the patterned sacrificial layer through the openings.

Examples of the present invention may also provide method of forming capacitive ultrasonic transducers, the method comprising forming a flexible layer on a substrate, forming a first conductive layer on the flexible layer, forming a patterned metal layer on the first conductive layer, forming a first polymer layer on the patterned metal layer and the first conductive layer, patterning the first polymer layer to provide a patterned first polymer layer, exposing portions of the patterned metal layer through openings, forming a patterned second conductive layer on the patterned first polymer layer, forming a patterned second polymer layer on the patterned second conductive layer and the patterned first polymer layer over the patterned metal layer, and removing the patterned metal layer through the openings.

Additional features and advantages of the present invention will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The features and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

The foregoing summary, as well as the following detailed description of the invention, will be better understood when read in conjunction with the appended drawings. For the purpose of illustrating the invention, there are shown in the drawings examples which are presently preferred. It should be understood, however, that the invention is not limited to the precise arrangements and instrumentalities shown.

In the drawings:

FIG. **1** is a schematic cross-sectional view of a conventional capacitive ultrasonic transducer;

FIGS. **2**A to **2**D are cross-sectional diagrams illustrating a conventional method for fabricating a capacitive ultrasonic transducer;

FIG. **3** is a schematic cross-sectional view of a flexible capacitive ultrasonic transducer consistent with an example of the present invention; and

FIGS. **4**A to **4**J are schematic cross-sectional diagrams illustrating a method of fabricating a flexible capacitive ultrasonic transducer consistent with an example of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Reference will now be made in detail to the present examples of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

FIG. **3** is a schematic cross-sectional view of a flexible capacitive ultrasonic transducer **30** in accordance with one example of the present invention. Referring to FIG. **3**, the flexible capacitive ultrasonic transducer **30** includes a flexible base **39**, a first electrode **31**, a support frame **35**, a membrane **38** and a second electrode **32**. The flexible base **39** may be made of a material such as, for example, polymer or other suitable material that may allow the capacitive ultrasonic transducer **30** to conform to a surface of an object. In one example, the flexible base **39** may have a thickness of approximately 0.45 micrometer (μm), the first electrode **31** may have a thickness of approximately 0.2 μm, and the second electrode **32** may have a thickness of 0.5 μm. The first electrode **31** may include a metal film made of platinum (Pt) or aurum (Au), and the second electrode **32** may include a metal film made of aluminum (Al). The first electrode **31** and the second electrode **32** may serve as a positive electrode and a negative electrode, respectively, of the capacitive ultrasonic transducer **30**. The support frame **35** and the membrane **38** may be made of polymer. In one example, the membrane **38** has a thickness of approximately 2 μm and the support frame **35** separates the first electrode **31** and the membrane **38** by a distance of approximately 2 μm. A cavity **36** is defined by the first electrode **31**, the support frame **35** and the membrane **38**.

FIGS. **4**A to **4**J are schematic cross-sectional diagrams illustrating a method for fabricating a flexible capacitive ultrasonic transducer in accordance with one example of the invention. Referring to FIG. **4**A, a substrate **40** is provided to serve as a supporting base on which flexible capacitive ultrasonic transducers may be fabricated. The substrate **40** may include a silicon substrate having a thickness of approximately 550 μm. A flexible layer **49**, which may eventually serve as a flexible base like the flexible base **39** illustrated in FIG. **3**, is formed on the substrate **40** by a conventional coating process or other suitable processes. A conductive layer **41** is formed on the flexible layer **49** by a conventional sputtering process of other suitable processes. The conductive layer **41**, which eventually serves as a first electrode for a capacitive ultrasonic transducer, may include a metal film such as a gold film.

Referring to FIG. **4**B, a patterned photoresist layer **42** is formed on the flexible layer **49** by a conventional patterning and etching process, exposing portions of the flexible layer **49** through openings **47**. The patterned photoresist layer **42** may include a polymeric material such as, for example, AZ4620. The pattern of the openings **47** may include but is not limited to a hexagon.

Referring to FIG. **4**C, a sacrificial metal layer **45** is formed to fill the openings **47** by a conventional electroplating process or other suitable processes. The sacrificial metal layer **45** may be substantially coplanar with the patterned photoresist layer **42**, and will be removed in a subsequent process so as to define a cavity. In one example according to the present invention, the sacrificial metal layer **43** includes copper (Cu).

Referring to FIG. **4**D, the patterned photoresist layer **42** is stripped and a first polymer layer **46** is formed over the sacrificial metal layer **43**. In one example according to the present invention, the first polymer layer **46** includes a polymeric material such as, for example, SU8-2002.

Referring to FIG. **4**E, the first polymer layer **46** illustrated in FIG. **4**D may then be lapped or polished by a conventional lapping or chemical machine polish (CMP) process. Next, a patterned first polymer layer **46-1** is formed by a conventional patterning and etching process, exposing portions of the sacrificial metal layer **43** through openings **43**. The patterned first polymer layer **46-1** subsequently serves as a support frame and at least a portion of a membrane for the capacitive ultrasonic transducer.

Referring to FIG. **4**F, a conductive layer **44** is formed over the patterned first polymer layer **46-1** and the sacrificial metal layer **45** by a sputtering, evaporating or PECVD process. In one example, the conductive layer **44** includes Al. Next, a photoresist layer **48** is formed over the conductive layer **44**. In one example, the photoresist layer **48** may include a positive photoresist, such as, for example, AZ5214E.

Referring to FIG. **4**G, a patterned conductive layer **44-1** is formed on the patterned first polymer layer **46-1** by a conventional patterning and etching process. The patterned conductive layer **44-1** subsequently becomes a second electrode for the capacitive ultrasonic transducer.

Referring to FIG. **4**H, a patterned second polymer layer **51** is formed over the patterned first polymer layer **46-1** and the patterned conductive layer **44-1**. The sacrificial metal layer **45** illustrated in FIG. **4**G is removed via the openings **43** through an etching process. In one example, the sacrificial metal layer **45** is removed by a wet etching process using ferric chloride ($FeCl_3$) as an etchant solution, which is etch selective so that the sacrificial metal layer **45** is removed without significantly removing the conductive layer **41**. Cavities **50** are therefore defined, but not sealed, by the conductive layer **41** and the patterned first polymer layer **46-1**.

Referring to FIG. **4**I, a patterned layer **52** may be formed to fill the openings **43** illustrated in FIG. **4**H. The patterned layer

52 may include a polymer layer. Cavities 50-1 are therefore defined and sealed by the conductive layer 41, the patterned first polymer layer 46-1 and the patterned layer 52. Next, referring to FIG. 4J, the substrate 40 is removed after the capacitive ultrasonic transducers are formed. The method illustrated in FIGS. 4A to 4J may be controlled at a temperature lower than approximately 150° C. (Celsius).

It will be appreciated by those skilled in the art that changes could be made to the examples described above without departing from the broad inventive concept thereof. It is understood, therefore, that this invention is not limited to the particular examples disclosed, but it is intended to cover modifications within the spirit and scope of the present invention as defined by the appended claims.

Further, in describing representative examples of the present invention, the specification may have presented the method and/or process of the present invention as a particular sequence of steps. However, to the extent that the method or process does not rely on the particular order of steps set forth herein, the method or process should not be limited to the particular sequence of steps described. As one of ordinary skill in the art would appreciate, other sequences of steps may be possible. Therefore, the particular order of the steps set forth in the specification should not be construed as limitations on the claims. In addition, the claims directed to the method and/or process of the present invention should not be limited to the performance of their steps in the order written, and one skilled in the art can readily appreciate that the sequences may be varied and still remain within the spirit and scope of the present invention.

We claim:

1. A method for fabricating capacitive ultrasonic transducers, the method comprising: providing a substrate;

forming a flexible layer on the substrate;

forming a first conductive layer on the flexible layer;

forming a patterned sacrificial layer on the first conductive layer; forming a first polymer layer over the patterned sacrificial layer;

patterning the first polymer layer to provide a patterned first polymer layer, exposing portions of the patterned sacrificial layer through openings;

forming a second conductive layer on the patterned first polymer layer;

patterning the second conductive layer to provide a patterned second conductive layer;

forming a second polymer layer over the patterned second conductive layer;

patterning the second polymer layer, exposing portions of the patterned sacrificial layer through the openings; and

removing the patterned sacrificial layer through the openings.

2. The method of claim **1**, further comprising:

forming a patterned polymer layer to fill the openings.

3. The method of claim **1**, wherein forming a patterned sacrificial layer on the first conductive layer comprises:

providing a photoresist layer on the first conductive layer;

patterning the photoresist layer to provide a patterned photoresist layer with openings;

forming a sacrificial layer to fill the openings; and

removing the patterned photoresist layer.

4. The method of claim **3**, wherein forming a sacrificial layer comprises:

electroplating a metal layer over the patterned photoresist layer to fill the openings.

5. The method of claim **1**, wherein the first polymer layer and the second polymer layer include substantially the same material.

6. The method of claim **1**, wherein the first polymer layer and the second polymer layer include SU8-2002.

7. A method of forming capacitive ultrasonic transducers, the method comprising: forming a flexible layer on a substrate;

forming a first conductive layer on the flexible layer;

forming a patterned metal layer on the first conductive layer;

forming a first polymer layer on the patterned metal layer and the first conductive layer;

patterning the first polymer layer to provide a patterned first polymer layer, exposing portions of the patterned metal layer through openings;

forming a patterned second conductive layer on the patterned first polymer layer;

forming a patterned second polymer layer on the patterned second conductive layer and the patterned first polymer layer over the patterned metal layer; and

removing the patterned metal layer through the openings.

8. The method of claim **7**, wherein forming the flexible layer on the substrate includes forming a polymer layer on the substrate.

9. The method of claim **8**, wherein the patterned first polymer layer and the patterned second polymer layer include substantially the same material.

10. The method of claim **8**, wherein the patterned first polymer layer and the patterned second polymer layer include SU8-2002.

11. The method of claim **8** further comprising forming a patterned third polymer layer to fill the openings.

12. The method of claim **7**, wherein forming the first conductive layer on the flexible layer includes forming one of a platinum and a gold film on the flexible layer.

13. The method of claim **7**, wherein forming the patterned metal layer on the first conductive layer further includes:

providing a photoresist layer on the first conductive layer;

patterning the photoresist layer to provide a patterned photoresist layer with openings;

forming a metal layer to fill the openings; and

removing the patterned photoresist layer.

14. The method of claim **13** further comprising electroplating a metal layer over the patterned photoresist layer to fill the openings.

15. The method of claim **13** further comprising electroplating a copper layer over the patterned photoresist layer to fill the openings.

* * * * *